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Major diseases and pathogen ecology of cabbage

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Abstract
Disease ecology means, the study of organisms that cause plant diseases in relation to their environment. Diseases are caused by pathogens (disease organisms) that include fungi, bacteria, viruses and nematodes. Most pathogens spread from infected plant material or soil. They are carried by wind, water (rain, irrigation water, ground water), insects, and by humans or tools (attached to clothing or shoes, and spread by pruning or cultivation tools). Cabbage is an important component of the human diet and a source of chemoprotective phytochemicals. Six major diseases of cabbage found worldwide are black rot, clubroot, black spot (dark spot), downy mildew, watery soft rot (white mold), and wirestem. The pathogens causing black rot and black spot can be seedborne. The pathogens causing clubroot, watery soft rot, and wirestem are soilborne; the clubroot organism is remarkably difficult to eradicate from infested soils. Important control measures include seed treatment with hot water or fungicides, crop rotation to reduce survival of foliar pathogens, scouting to detect disease outbreaks, and judicious application of protectant fungicides. Further research is needed to clarify races of the downy mildew and club root pathogens and to find useful resistance to these two diseases. Cabbage diseases are the chief limiting factor in profitable commercial cabbage growing in India. The most destructive of these are black leg, black-rot, and cabbage yellows. Any one may destroy the greater portion of a crop.

Keywords: Major diseases pathogen ecology of cabbage

Introduction
Cabbage (Brassica oleracea ‘‘Capitata Group’’) has long been cultivated as an important vegetable crop and a source of vitamins, minerals, and fiber, particularly during cold seasons in temperate climates [1]. More recently, cabbage and other cruciferous vegetables (members of the Brassicaceae) have been recognized as important sources of chemoprotective phytochemicals in the diet. Cabbage is a productive vegetable based on biomass per area of cultivation. However, this crop is affected by many diseases, particularly those caused by fungi and bacteria. This entry focuses on six diseases of worldwide importance in cabbage production. These diseases also affect other cole crops, i.e., vegetables derived from *B. oleracea*, including broccoli, Brussels sprouts, cauliflower, collard, kale, and kohlrabi, and other genetically related cruciferous vegetables, such as turnip, rutabaga, Chinese cabbages, and mustards. Emphasis will be placed on stages in the life cycles of the pathogens that affect management. Control measures will be presented in an IPM context. Diseases of leafy vegetables can cause devastating effects to crop. They can completely kill the crop or significantly reduce its quality, which means that we can incur great losses if one of the diseases strikes in the crop [1]. Leafy vegetables refer to crops such as: collard green, kale, cabbage, spinach, broccoli, rape, cauliflower, lettuce, celery and turnip, among others. They belong to the family- Cruciferae. There are several diseases that attack leafy vegetables, and they are majorly caused by fungi, bacteria or viruses. If we grow greens or planning to grow them, here are the common diseases of leaf vegetables, their causes, prevention, control and treatment. In this age of technology, biotechnology has opened up new horizons in the field of science. It is a viable option, which can provide improved genotypes that can survive under changing climate. Advancements in fields of genomics, stress biology and bioinformatics can help in development of stress tolerant crops [2].

How pathogens move to new plants
Unlike insects, pathogens cannot walk or fly onto a plants. Nematodes can crawl for a few centimeters looking for plant roots. But most pathogens must be carried (for example, by wind or rain), or else the tea bush must come to them (for example, a tea root growing towards a fungus spore).

Nonetheless, diseases can spread quickly from one plant to another, and also from one field to the next and even one village to another [7]. Some common ways in which pathogens spread are described here.

Direct transmission through
Seed: pathogens can be carried on or inside a plant seed.

Vegetative plant parts: infected transplants may carry diseases from nursery to the main field. Similarly, diseases can be transmitted from the mother bushes by infected cuttings.

Indirect transmission through
Growth of the pathogen: Fungi can spread over short distances by growth of the mycelium. For example wood rotting fungi can spread through the soil from one tree or trunk to the next by active growth [5].

Wind: Fungi that produce spores on the surface of plants can be disseminated by wind. Examples are blister blight, gray blight, and (probably) dead twig diseases. There are examples of spores of some fungi that have been found over 4000 m above an infected field! Often wind blows the spores over certain distances and then rain may deposit the spores down onto another field. Some bacteria can be dispersed by wind-blown rain [5].

Water: Flood or irrigation water may carry pathogens or spores, especially those in or near soil. The splashing of water during rain or heavy dews can spread fungal spores and bacteria to different parts of the same plant or to neighboring plants. An example of a water-carried pathogen is bacterial shoot blight; the secondary spread from initial infection results largely from splashing during rains. Water is not as important as wind for long-distance dissemination [4].

Soil: Soil can contain plant debris that is infected with pathogens. Soil can also contain spores of fungi and bacteria, and larvae of nematodes. So, diseases can spread whenever soil particles are transported, for example attached to seedling roots or attached to tools or people's shoes [9].

Insects, mites, nematodes: Small animals can move pathogens "by accident" when spores stick to the body of an insect or mite moving from one plant to another. More important is the case of some sucking insects that act as vectors. When vectors feed on a plant that is sick with virus, their mouthparts or saliva glands become contaminated with the virus pathogen. Then, when the vector moves to a healthy plant and starts feeding, the pathogen can enter the healthy plant and infect it. Most vectors are sucking insects such as aphids, whiteflies and leaf hoppers. Nematodes can also be vectors of pathogens [12]. Also, nematodes create small wounds on roots that are entry points for bacteria and fungi in the soil.

Humans and animals: Persons and animals spread diseases by walking and working in fields with infected plants, spreading spores sticking to the body. People also cause small injuries to plants (e.g. during transplanting, plucking, or pruning) that can be entry points for pathogens. Also, people can move a pathogen long distances by transporting diseased planting materials or infected soil particles [13, 16].

Major diseases and pathogen ecology
Leaf Spot and Blight (*Alternaria brassicae* and *A. brassiciola*): It is a destructive disease on seed crop. Older leaves are more susceptible. The initial symptoms are in the form of small dark yellow spots on the leaf surface. Later on the spots enlarge to circular areas with concentric rings and possibly surrounded by yellow halos. In severe cases, the entire plant defoliates. Violets to tan spots develop on infected cabbage seed pods which intensifies in wet weather [21].

Control: Use of disease free seeds, practicing proper crop rotation and seed treatment with hot water (50OC for 30 minutes) helps to minimize the disease incidence. Crops grown for seed purpose should be sprayed at full bloom, pod set and pre- harvest stage with Captan (0.2%) or Copper Oxychloride (0.5%) for the control of disease.

Black Rot (*Xanthomonas campestris* pv. c*ampestris)*: This bacterial disease is common in areas having a warm and wet climate. Plants can be infected during any growth stage and the symptoms resemble nutritional deficiencies. Infected seedlings become yellow, drop lower leaves, and may die. Leaves may be affected on only one side of a seedling. Plants infected because of contaminated seed may not develop symptoms for many weeks. The classic symptom of black rot is caused by local infection that results when bacteria enter leaves through natural openings of leaf margins. The infected tissue turns pale green-yellow and then turns brown and dies. Affected areas are usually wedge- or V-shaped. These areas enlarge as the disease progresses, and severely affected leaves may drop off. The veins in infected leaves, stems, and roots sometimes become black [22]. The heads of the infected plants remains small and its quality is reduced making it unfit for marketing.

Control: An integrated approach is needed to manage black rot successfully. Use of black rot tolerant varieties is the best method to control the disease. Considerable reduction in disease has been observed when seeds are treated with Agrimycin-100 (100ppm) or Streptocycline (100 ppm). Planting should be done on raised beds to facilitate drainage. Cultivation in the fields where crucifers have been continuously grown during last 2 years should be avoided. Plants should be thoroughly inspected for black rot symptoms and the affected plants should be removed and destroyed.

Downy Mildew *(Perenospora parasitica*): The disease is very serious in nursery and it can also appear in field planting. High humidity, fog, drizzling rains, and heavy dew favour the disease development and spread. The first symptom observed are small, light green-yellow lesions on the upper leaf surface, later showing on the undersurface. The spots turn yellow as they enlarge. During periods of high humidity, a grayish white moldy growth is developed on the undersurface of the leaf. Later the leaf may become papery and die. Cabbage heads develop sunken black spots. Though, some plants are infected at the seedling stage, the symptoms does not become apparent until near harvest [23].

Control: All the weeds serving as alternate host to the fungus should be destroyed. The crop should be irrigated judiciously to avoid periods of high humidity. Spraying the seedlings in the nursery beds with Copper Oxychloride (0.3%) is effective in controlling the disease. The first spray should be given as

soon as the seedlings appear. Subsequent sprayings are given at weekly intervals until the plants are transplanted in the field. For controlling the disease in the field, the crop is sprayed with Copper Oxychloride (0.5%).

Wire Stem (*Rhizoctonia solani)*: This disease is more serious in nursery beds. The affected young seedlings show reddish brown discolouration of the stem near the ground level. This area gets constricted and the plants bent or twist without breaking. In some cases, the seedling continues to grow even though the lesion girdles the stem. The lesion is quite sunken, and the stem resembles a wire, hence the name 'wirestem'. The girdled seedling eventually dies. Cool, cloudy weather, high humidity, wet and compact soil, and overcrowding especially favours development of the disease [25].

Control: Soil used for preparing raised beds should be well-drained. Excessive irrigation should be avoided to reduce humidity around the plants. The seedlings in the seedbed should be adequately spaced to allow maximum air movement. While transplanting, the seedlings showing symptoms of 'wirestem' disease should be discarded. Preventive measures such as seed treatment with antagonist fungal culture of Trichoderma viride (3-4 g/kg of seed) or Thiram (2-3 g/kg of seed) are effective. Soil around the affected seedling should be drenched with Dithane M 45 (0.2%) or Bavistin (0.1%) to control the spread of the disease.

Yellows or Fusarium Wilt *(Fusarium oxysporum* f. sp *conglutinans*): The disease affects the seedlings in nursery stage, however plants exhibit symptoms 2 to 4 weeks after transplanting. Disease development is promoted by warm weather conditions. Initial symptom appears as the development of yellowish green colour on one side of the plant. A lateral warping or curling of the stem and leaves occurs [3]. The lower part of the leaf blade adjoining the petiole or midrib wilts and dies. The lower leaves turn yellow and later the upper leaves are affected. With time, the yellow leaves turn brown and the affected tissue becomes dry and brittle [25]. The speed of progress of disease in the plant depends upon the degree of varietal susceptibility and the soil temperature.

Control: The conventional controls such as rotation, seed treatment, fungicide sprays, and destruction of crop refuse are of little value once the fungus has established itself on a farm or in a specific field. Therefore, the use of resistant varieties is the only control. However, as a preventive measure the vulnerable stage of the young seedlings to the infection can be avoided by very early sowing of cabbage.

Black Leg (*Phoma lingum*): This disease generally does not reduce seed crop yields; however, low levels of seed infection coupled with weather favorable for disease spread in seedbeds can lead to severe losses after transplanting. Pale, irregular spots develop on leaves, which later become ashy gray with scattered black dots on the surface. Stem lesions are elongated with purple borders near the ground level and extend below the soil surface, causing a black rot of lower stem and roots. Severely affected plants remain stunted and finally wilt. As plants mature, they fall sideways from lack of root anchorage. Seed crop symptoms include occasional cankers on stem bases and spots may appear on overwintered leaves. Symptoms on seed pods are rare and inconspicuous. Infection can spread to the base of leaves of cabbage heads in storage [19].

Control: Disease free seeds should be used for planting. As the main infection is through seeds, hot water treatment of seeds is recommended. For seed production plots, seed stock used should be free from fungal pathogen. Cultivation in the fields where crucifers have been continuously grown during last 2 years should be avoided. Seedbeds and seed plots should be regularly inspected for obvious foliar infections [18]. Seedlings before transplanting should not be dipped in water. Plant debris and disease susceptible weeds should be removed and destroyed.

Clubroot of Cabbage (*Plasmodiophora brassicae)*: Cool, wet and acidic soils favours the development and spread of the disease. Roots develop clubs (swellings) that can be 12-15cm wide. The largest clubs are usually on the larger roots just below the soil surface. Affected seedlings do not show any root swellings until about 3 weeks after infection. Infection in the nursery stage results in the death of seedlings. When plants are attacked at a later stage, the disease rarely kills the plant, but the capacity of the affected roots to absorb minerals and water gets reduced. Plants wilt in hot weather but partly recover at night. Finally leaves become stunted, yellowish and prematurely bolt in hot weather [17].

Control: Early infection of seedlings can be destructive, so it is important to use only uninfected seedbeds and clean equipment. Long rotations (6 years or longer) help prevent a pathogen buildup and reduce disease incidence. When susceptible varieties are grown in acidic soils, finely ground limestone is thoroughly mixed into the soil six weeks before planting to raise the soil pH above 7.0. Lime inhibits disease development, but will not prevent a disease outbreak if the spore load in the soil is sufficiently high. The quantity of lime is determined by initially measuring the pH of the soil.

Damping off (Pythium *debaryanum*): The disease causes severe damage in the nursery. Cool, cloudy weather, high humidity, wet soils, compacted soil, and overcrowding especially favor development of damping-off [15]. Damping-off kills seedlings before or soon after they emerge. Infection before seedling emergence results in poor germination. If the decay is after seedlings emergence, they fall over or die which is referred to as "damp-off." The destructiveness of the disease depends on the amount of pathogen in the soil and on environmental conditions. Seedlings that emerge develop a lesion near where the tender stem contacts the soil surface [11]. The tissues beneath the lesion become soft due to which the seedlings collapse.

Control: In the nursery, soil used for preparing raised beds should be well- drained. Excessive irrigation should be avoided to reduce humidity around the plants. Seed treatment with antagonist fungal culture of Trichoderma viride (3-4 g/kg of seed) or Thiram (2-3 g/kg of seed) and soil drenching with Dithane M 45 (0.2%) or Bavistin (0.1%) affords protection against the disease. The nursery should be regularly inspected for the disease affected seedlings. Such seedlings should be removed and destroyed [8].

Sclerotinia rot/ White Mould (*Sclerotinia sclerotiorum*): This fungus can cause serious losses in the field, in storage, and under transit and market conditions. Generally, damp weather favours the occurrence of the disease. Infections may occur on the stem at the ground level, on the leaves at their bases, or where the foliage comes in contact with the soil. The infections begin as water-soaked, circular areas, which soon become covered by white, cottony fungal growth. The affected tissue becomes soft and watery as the disease progresses. The fungus eventually colonizes the entire cabbage head and produces large, black, seedlike structures called sclerotia on the diseased tissue [14].

Control: The disease can be managed most successfully by combining cultural practices that discourage disease development. Planting cabbage in fields that are surrounded by dense woods will restrict air circulation and subsequently delay drying. Rows should be planted in the direction of the prevailing winds to promote free flow of air movement within the plants. Fields with a history of white mold should be planted with non-susceptible crops such as grains (corn, rye, wheat, etc.). Cabbage and other susceptible crops (cauliflower, beans, peas, etc.) should not be planted in fields where white mold has become a problem because continuous cropping of susceptible crops will result in a buildup of the fungus in the soil and increased disease incidence [10]. Mechanical injuries to cabbage heads during harvesting operations should be avoided.

Examples of integrated disease management

Controlling weeds, especially ragweed (*Ambrosia artemisiifolia*), can reduce incidence of watery soft rot. Ascospores of Sclerotinia infect ragweed flowers that then fall onto cabbage leaves and infect them, because flower parts provide nutrients for the pathogen. Control flea beetles (*Phyllotreta cruciferae*), which carry conidia of *A. brassisicola* on their bodies and in their frass and transmit conidia while feeding. Private and public cabbage scouting programs have been developed and are useful for scouting production fields for diseases and insects. For example, the cabbage scouting program in Suffolk County, New York, U.S.A., has operated for the past 20 years [4]. In addition to insects, scouts record the presence, general severity, and field location of black rot, black spot, clubroot, downy mildew, viruses, watery soft rot and yellows [6].

Managing seedborne pathogens

Plant seed from seedlots that have tested negative for the presence of the pathogens that cause black rot and black leg. Hot water seed treatment is useful to control seedborne black rot bacteria, provided the water temperature is monitored carefully so it remains at 50^0C for 25 minutes. Minimize leaf wetness periods when producing transplants in glasshouses, because of the ease of spreading pathogens. Apply protectant fungicides to seed crops to prevent infection of seed by Alternaria [5].

Managing soilborne pathogens

Soil fumigants generally are not used against soilborne pathogens in cabbage production because of the high cost, although they may be used to disinfest seedbeds and suppress clubroot. Field-grown transplants may be sources of the wirestem and clubroot pathogens and spread them to non-infested fields. Because of this risk, transplants should be produced in soilless mixes in glasshouses when possible. Do not plant any cruciferous vegetables in fields before or after cropping to cabbage. Use monocots as rotation crops, because R. solani AG 4 has a wide host range among dicotyledonous crops. The resting spores of the clubroot organism cannot be eradicated by rotation. Instead, liming soil to raise the pH above 7.2 with calcium oxide or hydrated lime prevents infection of roots in many soils [3].

Managing foliar pathogens

Diseases caused by foliar pathogens, such as Xanthomonas and Alternaria, can be managed with crop rotation during the period when infested host debris is decaying in affected fields, because these foliar pathogens of cabbage do not survive longer than one or two years in soil, respectively. Disk and bury or compost unmarketable cabbage heads. Apply protectant fungicides as needed based on environmental conditions and host susceptibility. Because Alternaria spp. require relatively long periods of leaf wetness for infection (a minimum of five to nine hours), disease can be reduced by increasing row width and plant spacing to promote air circulation that dries leaves [11].

Conclusions

Management means a range of activities that support each other. These activities should be done before transplanting of the crop, some even before sowing the seeds. Disease management is a long-term activity, sometimes it is a planning for several years. It is mainly focused on preventing the disease from coming into a field. It also aims at keeping disease pressure low in case a disease is present. Management usually needs the cooperation of several farmers working together to reduce overall diseases in an area. Control is a short-term activity, focused on killing a disease or stopping the spread of it. The trouble with diseases is that you only see them when you see the symptoms. That means infection already occurred at least a few days before. It also means that plants that look healthy today, may have disease symptoms tomorrow. Once a plant is infected, it is difficult to actually kill the pathogen. Especially when pathogens live in the soil and attack plants through the root system, they can only be controlled by proper management techniques like crop rotation or cultural methods. And those kind of methods usually have to be done before transplanting the crop [20]. The diseases black spot, downy mildew, watery soft rot, and wire stem often can be managed successfully using a combination of cultural, biological, and chemical control measures. The cultural and biological methods are amenable to organic production systems. Management of black rot and clubroot remains more challenging. In the future, resistance to downy mildew and improved resistance to black rot may be available in cabbage cultivars. It may be possible to transfer downy mildew resistance from broccoli to cabbage using molecular genetics methods. Additional research is needed to clarify the identity of races of the downy mildew and clubroot organisms. Spraying fungicides, a typical short-term activity, may be a control option but only for a limited number of diseases and usually only partially. So a combination with cultural practices like sanitation is essential! It should be noted that some fungicides can kill natural enemies of insects. For example, copper-based fungicides can cause increased problems with mites. In order to make a good disease management decision, you have to know a few basic things about the disease. Things like: where does it come from, and

how does it spread. Knowing this will give you a clue how to manage it. Soil-borne diseases are managed differently from wind-borne diseases. A disease is the result of interactions between three things: a pathogen, a host plant and the environment. These interactions are shown in the disease triangle: a. The disease triangle shows that a plant will get infected with a disease only when: the variety of that plant is susceptible to the disease, b. the disease is present and virulent (able to infect the plant) and c. the environment (e.g. humidity, temperature, and natural enemies) is favorable for the disease to develop.

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